Experiments Summary Report

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Defense against impacts by comets and asteroids is unlikely to be successfully implemented without comprehensive experimental projects to greatly expand and enhance our present state of knowledge. The census of objects that potentially threaten the Earth is currently very incomplete in terms of population energetics, distribution in phase space, and knowledge of inherent physical characteristics. In addition to a robust survey effort to discover and determine the orbital characteristics of a (hopefully!) nearly complete sample of the largest threatening objects, many other types of observations and experiments must be carried out if a true defensive capability is to evolve.

Some of the needed experiments could take the form of comprehensive *remote* probing, for example, by using sophisticated radar imaging to establish the shape and probably composition of many objects as they pass near the Earth. Other useful physical experiments on strength of materials and response characteristics to energy inputs of various forms can be performed on Earth by utilizing recovered meteorites, surrogate metallic or stony objects composed of earth materials, and/or detailed computer models. Ultimately, however, there must be space experiments that sample, probe, and perturb objects *in situ* to fully establish the responses of real objects of all major classifications. This will lead eventually to demonstrations of the ability to actually alter orbits or completely disrupt sample objects. The latter class of mature experiments will necessarily be performed in ways that will pose no possible threat to the Earth.

Not only will such experiments yield the knowledge base required for true impact mitigation, they will also provide a wealth of new data on the origin and history of the solar system. Each class* of objects will retain different thermal, isotopic, molecular, and geometrical epochal records of origin and evolution that will yield orders of magnitude more accurate scientific detail than previously available. In this regard, it is important to remember that the Apollo and Lunakhod lunar samples are the only virgin extraterrestrial materials yet in captivity; but the Moon was clearly subjected to profound and unique transformations early in its evolution that make its historical record also uniquely biased. In a sense, meteorites collected on the Earth - be they from parent asteroids, comets, Mars, or the Moon - provide a more encyclopedic record of the history of the solar system than the lunar samples, although there remain many uncertainties concerning the times and places of origin of most meteorites and the environmental modifications that they have experienced before, during and after their arrival on the Earth. So there are exciting troves of scientific wealth awaiting discovery in the future when detailed and comprehensive *in situ* sampling of Near Earth Objects becomes feasible.

For these reasons, the organizers of the Lawrence Livermore National Laboratory workshop on Planetary Defense deemed it important to have a panel study devoted to the topic of NEO Experiments. The panel members who participated are shown in Table 1. To guide their deliberations, they formulated the statement of goals and consensus reproduced in Table 2. It can be seen that these goals closely reflect the motives described above.

The Experiments Panel generated an outline of a set of steps leading from theory and laboratory experiments to space flyby and probe experiments. These efforts would

* Classification Definition: (0) comet-like, (1) carbonaceous chondrite-like, (2) stony, (3) iron-nickel, (4) breccia or rubbish pile

Table 1: Panel Members (Experiments)

J. Mansfield, NASA Headquarters (Co-Chair)

S. Nozette, Phillips Laboratory, USAF (Co-Chair)

J. Remo, Quantametrics Inc.

D. Chriswell, University of Houston

J. Degnan, Phillips Laboratory, USAF

P. Hammerling, Quantametrics Inc.

W. Huebner, NASA Headquarters

A. Ledebuhr, Lawrence Livermore National Laboratory

J. Lewis, Lunar and Planetary Laboratory, University of Arizona

E. Tagliaferri, ET Space Systems

W. Tedeschi, Sandia National Laboratory

W. Wattenberg, CSU

Table 2: Experiments Panel Goals and Consensus

I. Gain knowledge of the physical properties and response characteristics of NEOs. Such knowledge can be utilized for :

- Understanding the origin and evolution of the solar system.
- Identification and tracking of NEO families.
- Providing data to predict behavior of NEOs in response to deflection techniques.
- Systematically establishing data on NEO material properties.
- Providing a basis for physical understanding of mitigation options.
- Facilitating effective resource uses.

II. Articulate issues

III. Develop an experiments strategy

IV. Reach a consensus of the experts

establish the basis for a mitigation options matrix. A set of carefully diagnosed interaction experiments in space was proposed, employing technologies potentially useful for subsequent applications in a prototype interception capability. These experiments would culminate in full-scale kinetic impacts on selected NEOs, including precise measurements of orbital alterations. The diagnostic data gleaned from both ground-based and space based measurements would then provide full understanding of the energy transfer mechanisms. This would, in turn, provide a basis for simulating the expected behavior of intercept interactions with higher energy NEOs.

Principal topics of the panel work were defined by three major experimental categories, namely (1) laboratory (i.e. ground-based) experiments and associated computational modeling, (2) satellite observations of the Earth using existing or improved new surveillance satellites to detect and diagnose atmospheric impacting objects and guide sampling missions to debris clouds and meteorite finds, and (3) spacecraft probes to NEOs to yield (a) fly-by imaging, (b) hard impact diagnostics, (c) detailed rendezvous remote sensing to determine composition and mass distribution, and (d) *in situ* surface experiments.

Panelists also considered the types of instrumentation required to maximize data collection for specific missions. Examples include all types of spectrometers (i.e. optical, particle, gamma ray, x-ray, and mass), radiometers, magnetometers, gravitometers, seismometers, and impactors.

The sessions on laboratory experiments focused generally upon how to improve upon current understanding of the fundamental material properties and response characteristics of asteroids and comets. Such experiments include (a) constitutive models, (b) equation of state models, (c) radiation opacities and particle transport properties, (d) electromagnetic properties, (e) large scale mechanical and thermal properties, (f) mechanical and thermodynamic response to various energy fluences, and (g) global momentum deposition and body fragmentation characteristics. Some of these experiments would utilize actual meteorites, while others would use surrogates made from appropriate earth-derived materials. Other "experiments" will be strictly theoretical, analytical, or computational.

Computer simulations will be utilized in many ways, especially in extending understanding of effects and phenomenologies beyond what may be feasible in actual physical experiments at any given stage of development of mitigation capabilities. Complex hydrodynamic codes and radiative hydro codes are of fundamental importance in modeling impacts and disruptions. Radiation opacity codes are useful, for example, in determining blow-off effects of a hypothetical proximal nuclear explosion. Equation of state calculations, together with constitutive models, will enable realistic calculations of the response of simulated NEOs to nuclear and non-nuclear disruption attempts. Models of thermal, gaseous, or plasma diffusion pertain to the evolution and effects of the reaction mass in a blow-off-generating perturbation event. Activation and ionization models will yield synthetic spectra of gases and plasmas that may serve useful diagnostic purposes. Taken together, the ensemble of computer generated experiments and models will go far toward establishment of overall criteria for empirical validation of perturbation and disruption mitigation attempts.

The ultimate goal of experimentation building toward true mitigation capabilities is to perform *in-situ* space missions. Such missions will intimately explore the nature of NEOs and their response to perturbations. The New Millennium and Discovery class small spacecraft missions now being planned will lead to sophisticated diagnostic instrumentation and eventually to the return of material samples to the Earth. Transponders and other *in-situ* diagnostic tools deposited on or beneath the surface of NEOs will permit computed tomography of the internal mass distribution and structure of selected objects. A large suite of diagnostic instruments will observe and measure the effects of impactors.